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Publication date:
2009

Document Version
Publisher's PDF, also known as Version of record

[Link to publication from Aalborg University](#)

Citation for published version (APA):

Kristensen, A. H., Henriksen, K., Mortensen, L., & Møldrup, P. (2009). ***Biodegradation of Petroleum Vapors in Layered Subsurface Sediments: Effects of Variable Soil Physical Conditions***. Poster presented at Microbial Degradation of Soil Pollutants, København, Denmark.

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Biodegradation of Petroleum Vapors in Layered Subsurface Sediments: Effects of Variable Soil Physical Conditions

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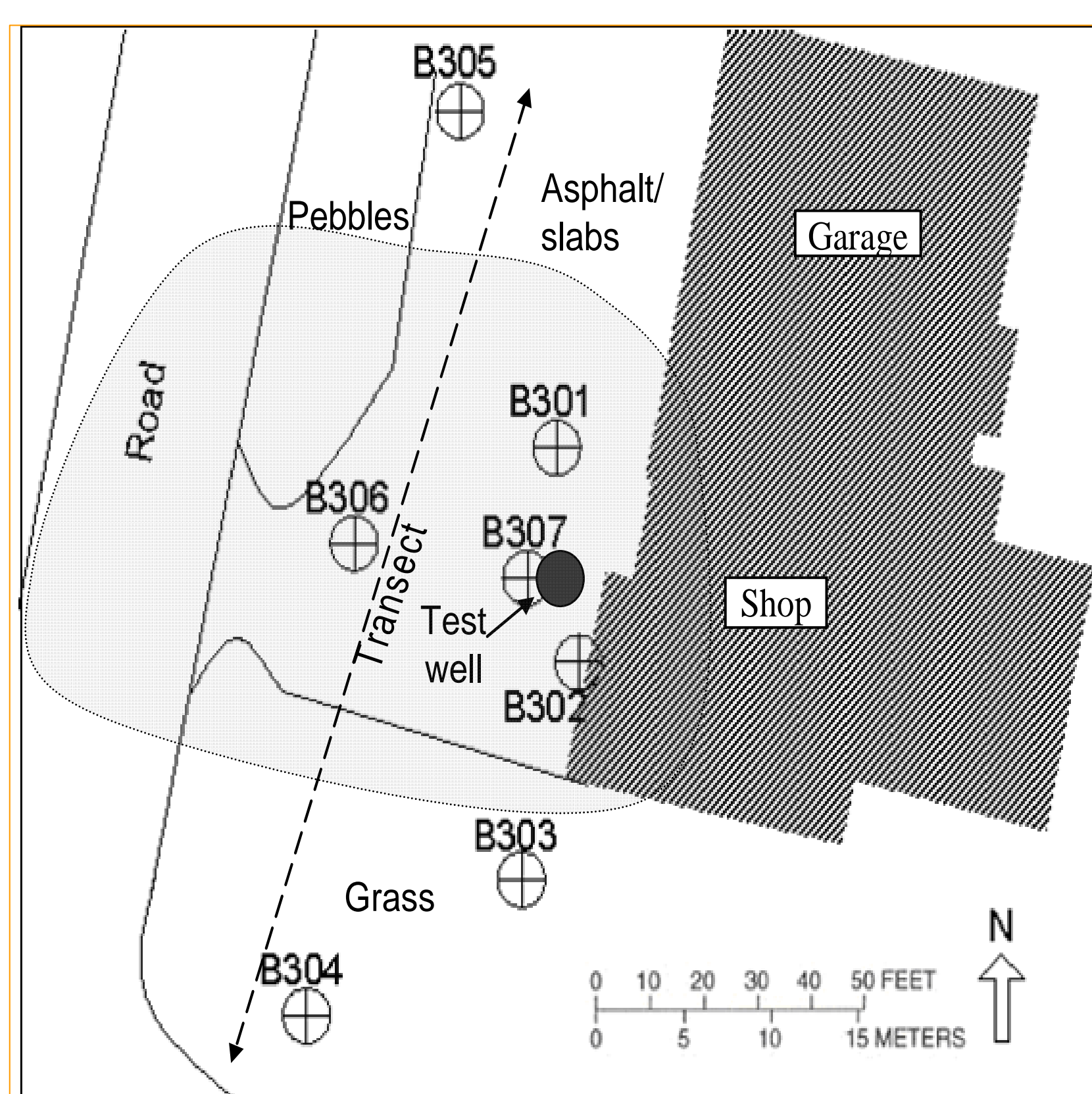
1 INTRODUCTION

Naturally occurring biodegradation of petroleum vapors in the unsaturated zone depends on the physical soil environment influencing field-scale gas-exchange and pore-scale microbial metabolism. In this study we evaluated the effect of soil physical heterogeneity on biodegradation of petroleum vapors. The study included a laboratory and a field investigation of a 16-m-deep, layered vadose zone contaminated with petroleum hydrocarbons. The site was interesting because hydrocarbon-degrading bacteria were dominating due to low contents of natural organic matter. The objective was to link the potential for subsurface biodegradation to the variable physical soil characteristics. First, soil samples were collected from all major soil layers and characterized in the laboratory in terms of soil texture, water content, air-filled porosity, concentration of total petroleum hydrocarbons (TPH), and direct counts of soil bacteria. Second, soil slurry experiments using benzene amendment to suspended soil samples were performed to determine aerobic biodegradation potentials under well-mixed conditions, reflecting the size of benzene-degrading populations at the time the experiments were set up. Third, in situ respiration tests were conducted in different textured soil layers to compare with laboratory data.

2 MATERIALS AND METHODS

Soil sampling. The study was carried out in Nyborg, Denmark, at a former petrol station. Seven boreholes (B301-B307, see below map) were drilled using SonicSampDrill® and GeoPrope®. Intact soil cores (diameter = 50 mm) were extracted from 2-16 m below ground level in the unsaturated zone. From these cores, a total of 100 samples of loose soil were collected.

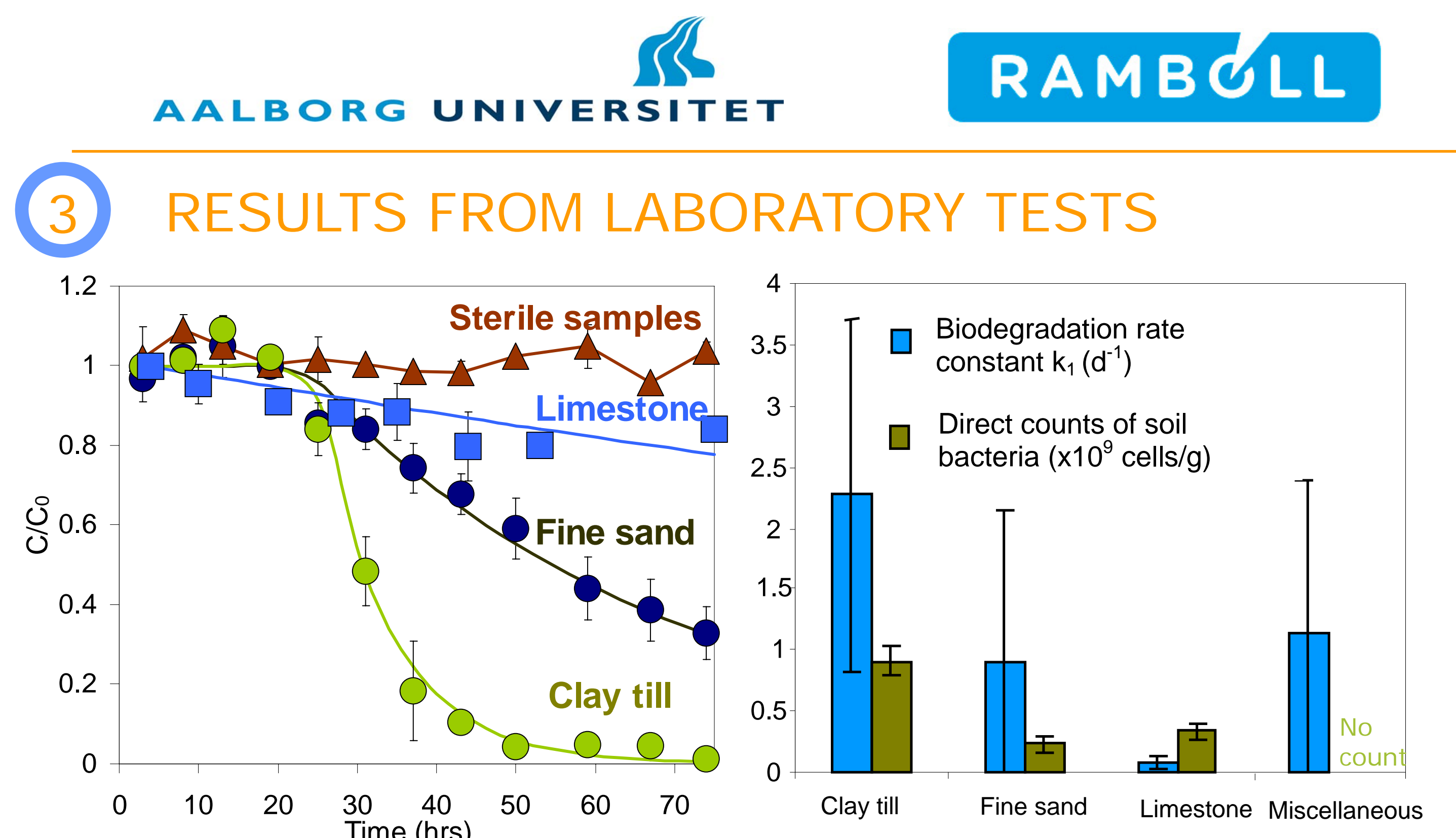
Laboratory tests. Short-term slurry experiments (soil-water ratio 10:30 w/w, 25 °C, 75 hr) on potential aerobic biodegradation of benzene were performed. Gaseous benzene was injected to the headspace, achieving a final dissolved concentration of about 3 mg benzene L⁻¹. Gas sample analysis was carried out using GC-FID. A first-order rate model including lag phase was fitted to each set of data (dissolved benzene concentration vs. time). All soil slurry experiments were performed in duplicate.



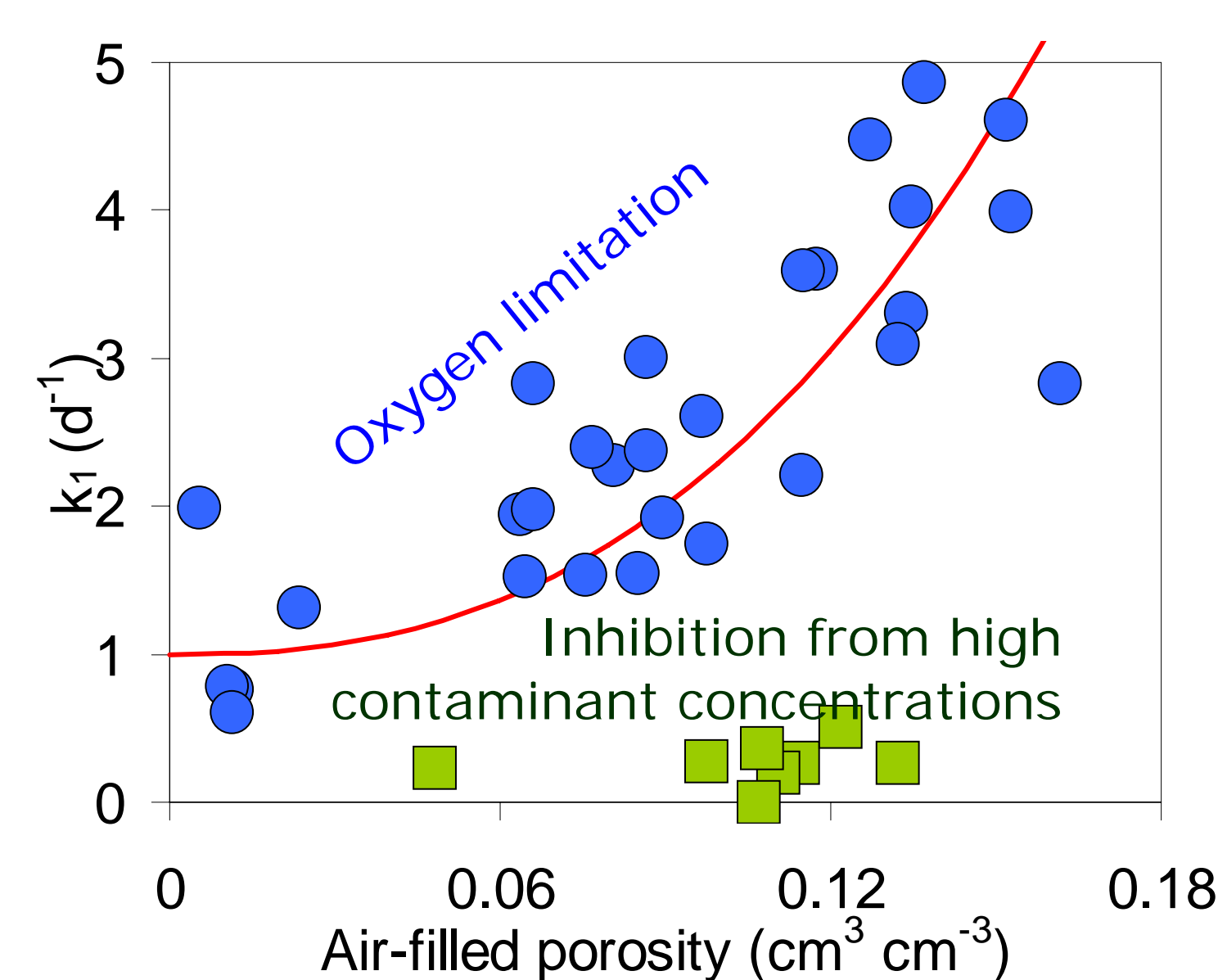
In situ respiration tests
Atmospheric air was injected in two different unsaturated soil layers (clay till and fine sand) in a multi-screened test well for 24 hours. After aeration ended, oxygen and carbon dioxide concentrations were monitored in individual injection screens for 3 days.

The study site and estimated area that was impacted by soil pollution (mainly BTEX).

Photo of a GeoPrope® drilling conducted at the study site to collect intact soil cores.

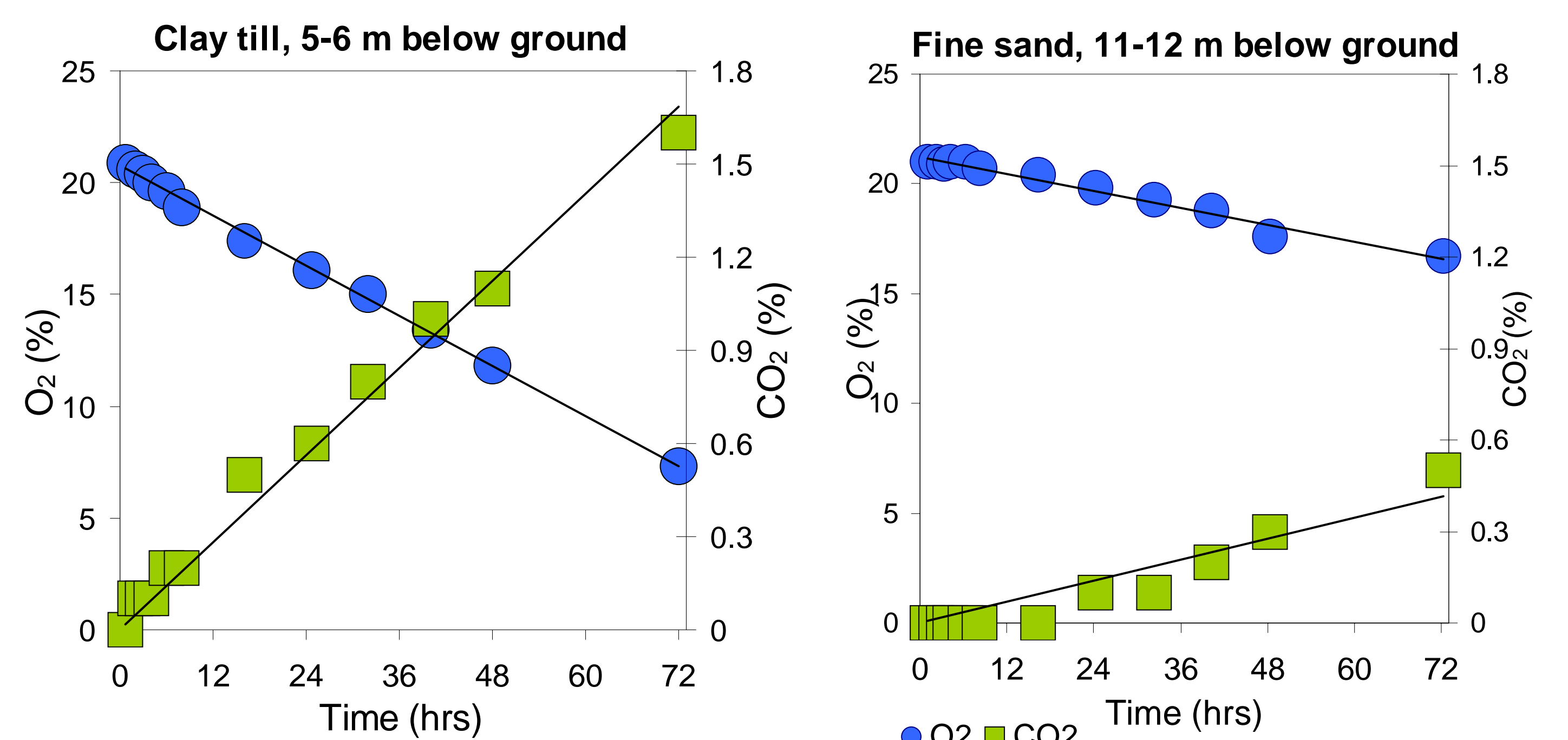


Slurry reactor biodegradation of benzene and direct cell counts in different textured soil samples.



(left) First-order rate constants compared to the size of the soil air-filled porosity, (right) slurry reactors used for laboratory tests.

4 RESULTS FROM IN SITU RESPIRATION TESTS



Results from in situ respiration test in deposits of clay till and fine sand, respectively.

5 CONCLUSIONS

- Laboratory biodegradation potentials in different textured soil samples were related to soil type (rather than depth) in the order: clay till > fine sand > limestone.
- Similarly, oxygen consumption rates during in situ respiration tests were higher in deposits of clay till than in fine sand.
- Laboratory and field data both indicated aerobic biodegradation rates in the order of ~1 mg TPH kg⁻¹ day⁻¹ (10 °C), suggesting bioremediation to be applicable despite nutrient-limited subsurface conditions.
- In slurries, the biodegradation potential tended to decline with increasing water saturation in the field. This suggested air-filled porosity to be a key factor for the intrinsic biodegradation potential.

6 ACKNOWLEDGMENTS

This project was financed by Rambøll Denmark A/S and The Danish Agency for Science, Technology and Innovation under the Industrial PhD Scheme. In addition, thanks is due to the Danish Oil Industry's Environmental Fund (OM) for allowing access to the study site.